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Indian Standard

IS 4961 : 2022

वायु एल्यूट्रियेशन विधि द्वारा पाउडर के कणों के आकार का निर्धारण

(पहला पुनरीक्षण)

Determination of Particle Size of Powders by Air Elutriation Methods

(First Revision)

ICS 19.120

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भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS
मानक भवन, 9 बहादुरशाह ज़फर मार्ग, नई दिल्ली – 110002
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI-110002
www.bis.gov.in www.standardsbis.in

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Sieves, Sieving and Other Sizing Methods Sectional Committee, CED 55

FOREWORD

This Indian Standard (First Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Sieves, Sieving and Other Sizing Methods Sectional Committee had been approved by the Civil Engineering Division Council.

This standard describes air elutriation methods for determining the particle size distribution in those fraction of powders which pass through a 75 micron IS Sieve.

Methods adopted for determination of size distribution should be such that conditions of test are similar to conditions of use. For example, powders used in wet processes should be tested by liquid sedimentation. A dry powder used in air dispersed condition may be analysed by air elutriation. Such co-ordination, however, is not always necessary or possible.

The choice of the most suitable method for determination of particle size depends, in addition to the factors stated under above, and on the following factors like:

a) the purpose for which the analysis is required,
b) the size range and density of particles,
c) the important properties of powder,
d) the amount available for test, and
e) the method by which the gross sample has been collected.

This standard was first published in 1968. This revision incorporates modifications with the intention of obviating ambiguity and confusion arising out of varying individual interpretations of different terms related to particle size of powder. It includes definitions of certain additional terms whose inclusion has become essential, and also modifies definitions of certain terms in line with international practice.

The composition of the Committee responsible for the formulation of this standard is given at Annex C.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 ‘Rules for rounding off numerical values (*second revision*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

DETERMINATION OF PARTICLE SIZE OF POWDERS BY AIR ELUTRIATION METHODS

(First Revision)

1 SCOPE

This standard covers three methods of air elutriation for quantitative determination of particle size distribution in sub-sieve range. The first method suitable for readily dispersed particles is used for particle size range 5 to 75 microns. The second method is suitable for poorly dispersed particles in the same size range. The third method is suitable for dealing with particles which are difficult to disperse and are in size range of 10 to 75 microns.

2 REFERENCES

The following standards contain provisions, which through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standard indicated below:

IS No.	*Title*
460 (Part 1) : 2020	Test sieves — Specification: Part 1 Wire cloth test sieves (*fourth revision*)
4124 : 1981	Glossary of terms relating to powders (*first revision*)

3 TERMINOLOGY

For the purpose of this standard, the following definitions and those given in IS 4124 shall apply.

3.1 Analysis Sample — The portion of the laboratory sample which is used in the size analysis apparatus.

3.2 Elutriation — The process for separating a mixture of minerals into two or more products utilizing the difference in settling velocity between particles to effect this separation. For the purpose, an upward flow of water runs countercurrent to the material flow in a hollow elutriation column.

3.3 Laboratory Sample — The portion of the gross sample which is delivered to the laboratory for determination of particle size distribution.

4 BASIC PRINCIPLE OF ELUTRIATION METHODS

4.1 Elutriation methods are based on the measurement of the proportion of the powder which is carried off by an upward flow of gas in a vertical column at a known velocity. The largest size of particle elutriated by a given gas velocity is calculated from Stoke's law:

$$U_t = \left(\frac{d_{stk}^2 \, (\rho_S - \rho_f) \, g}{18 \, \mu} \right)$$

where

U_t = Terminal settling velocity of settling particle, in m/s;

d_{stk} = Stoke's diameter of the particle, in microns;

μ = Viscosity of the medium, in Pa.s;

ρ_s = Density of settling solid particle in the fluid, in kg/m^3;

ρ_f = Density of liquid medium, in kg/m^3; and

g = Acceleration due to gravity, in m^2/s.

4.1.1 Equation in **4.1** is valid only in the Stoke's region of viscous flow determined by the magnitude of the Reynolds number, which should not exceed 0.2, if the error is not to exceed 5 percent (*see* Annex A). Reynolds number is given by the following equation:

$$\frac{U_t . d_{stk} . \rho_f}{\mu}$$

where

U_t = Free fall velocity of the particle, in m/s;

d_{stk} = Stoke's diameter of the particle, in microns;

ρ_f = Density of the fluid, in kg/m^3; and

μ = Viscosity of air, in Pa.s.

4.2 The minimum value of the linear gas velocity necessary to elutriate a particle of diameter *d* is its free falling speed, υ. The corresponding volume rate of gas flow, Q is given by the following equation:

$$Q = \frac{\pi D^2 v}{4} \text{m}^3 / \text{s}$$

where

D = Diameter of the elutriator tube, in mm; and

v = U_t = Free-falling velocity of particle in mm/s.

4.3 In a determination of size distribution, the velocity in the column is adjusted to carry off particles smaller than the upper limit of the smallest size fraction. The residue is weighed and the velocity increased to carry off the next smallest fraction of the particles remaining in the residue. This process is repeated until the full size range has been covered.

5 PREPARATION OF THE ANALYSIS SAMPLE

The analysis sample is prepared as follow:

a) Air-dry the sample;
b) Carefully break down large aggregates;
c) Sieve on a 75 micron IS Sieve [*see* IS 460 (Part 1)] and record the percentage weight of sample remaining on the sieve;
d) Subdivide the portion which has passed through the sieve and necessary to provide the analysis sample;
e) Determine the density of particles;
f) Dry the sample at 110 °C (if permissible);
g) Cool in a desiccator;
h) Disaggregate again, if necessary;
j) Weigh the elutriator powder container;
k) Put the analysis sample into the container; and
m) Re-weigh.

6 DISPERSION

For accurate measurement of particle size distribution it is essential that the particles should be freely dispersed. The main difficulty is to break down or prevent the formation of aggregates without fracturing the individual particles. This may be achieved to some extent by the gas or solid distributor systems of the elutriators. Nevertheless, the powder should be as finely dispersed as possible before it is fed to the distributor. A method which is applicable to most, but not all powders, is to extract them successively with a dehydrated liquid followed by highly volatile liquid, for example, methods as gentle rolling under a glass rod or brushing with a short camel hair brush. The suitability of a method for any particular powder may be ascertained only by trial experiments.

7 AIR OR GAS SUPPLY

7.1 The methods refer to air as the elutriating medium, although other gases may be used if the powders react in any way with air, provided that the values of viscosity and density appropriate to the chosen gas at the operating temperature and pressure are inserted in equation given in **4.1**.

7.1.1 All elutriators need to be supplied with clean, dry gas at inlet (gauge) pressures usually between 0.3 to 1.0 kg/cm^2. Water vapour is removed by a conventional drying train, and oil mist by filtration through an inch layer of superfine glass wool.

8 AIR ELUTRIATION METHODS

Three types of elutriators are as follows, which are described in **9**, **10** and **11**:

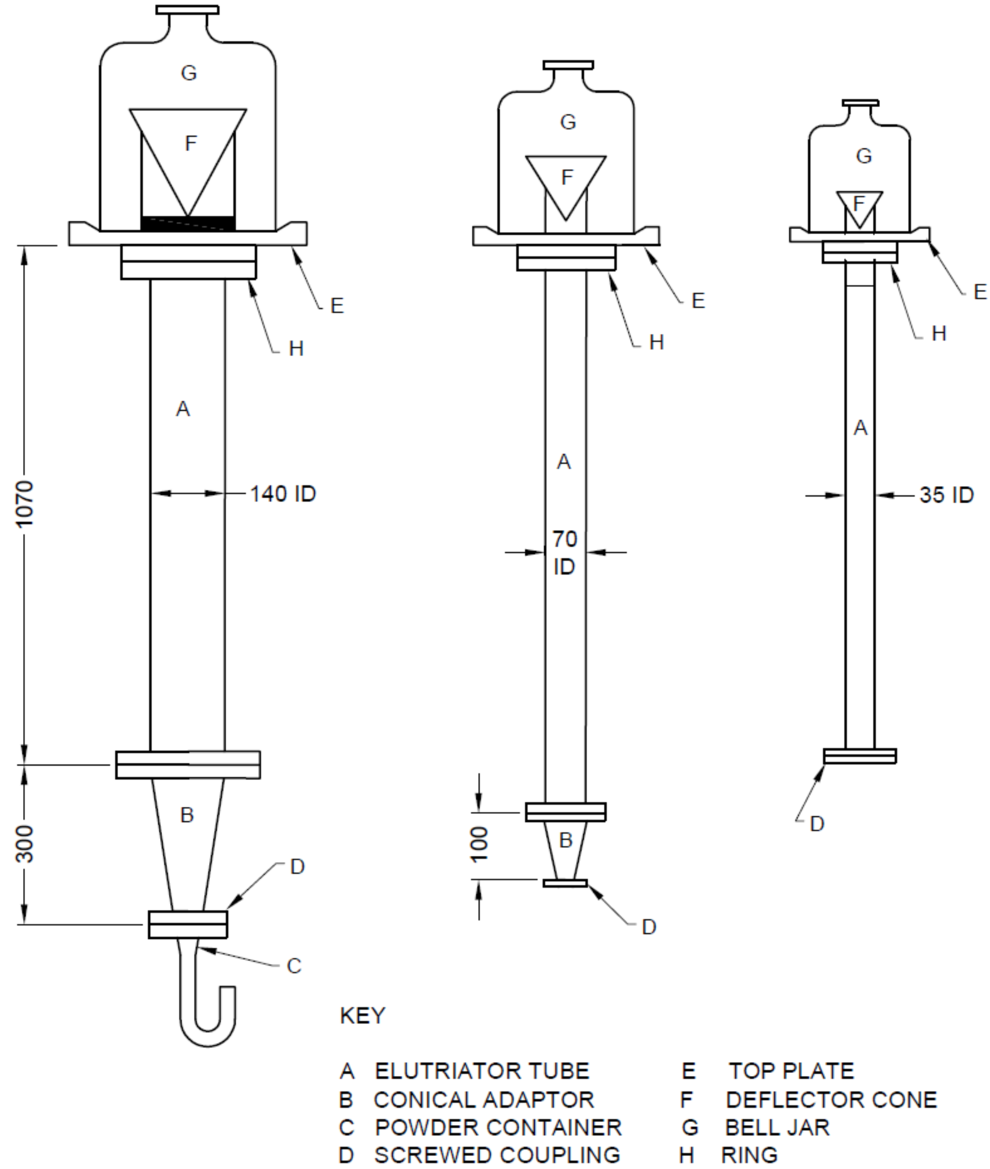
a) Gonell elutriator,
b) Roller elutriator, and
c) Miniature elutriator.

9 GONELL ELUTRIATOR

9.1 Apparatus (*see* Fig. 1 to 4)

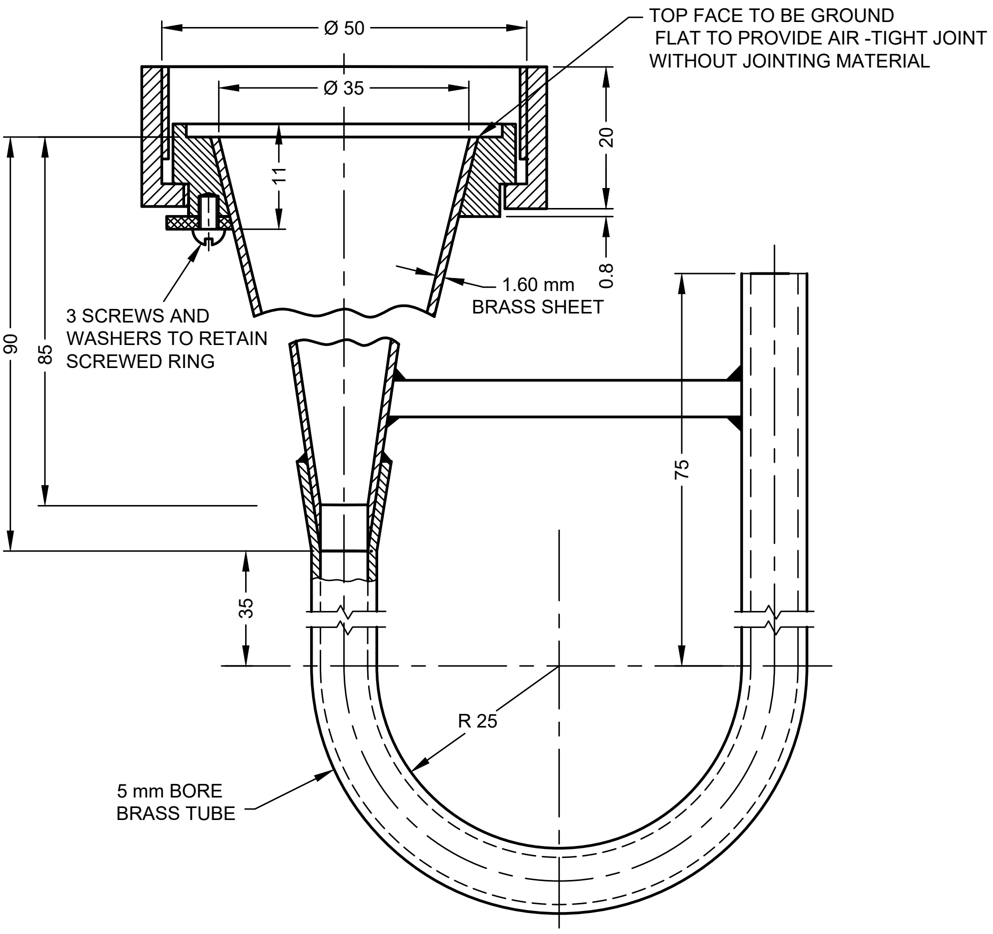
The Gonell elutriator is suitable for readily dispersed particles in the size range 5 to 75 microns. An analysis sample of 1 to 3 ml is required. Three tubes of different diameters are operated independently, the sizes being such that for the same volume rate of air flow passing through each, the maximum diameters of particles carried off are in the geometric ratio of 1 : 2 : 4. The apparatus described differs from the original Gonell apparatus in the design of the inlet injector. The following are the requirements of the apparatus:

a) *Elutriator* — Consists of three tubes each 1 070 mm long, the internal diameter of the tubes being 140 mm, 70 mm and 35 mm respectively. The tubes are made of brass and are internally plated with nickel or chromium. The inside surface shall be free from ripples. At the base of each tube a small container which holds the analysis sample of powder to be examined. The two larger tubes are connected to the container by conical extensions. The three tubes are set truly vertical. This is essential in order to minimize the amount of dust which may deposit on the walls of the tubes. A vibrator of robust construction shall be attached to the tube in use to assist in dislodging or preventing particles from adhering to the walls.



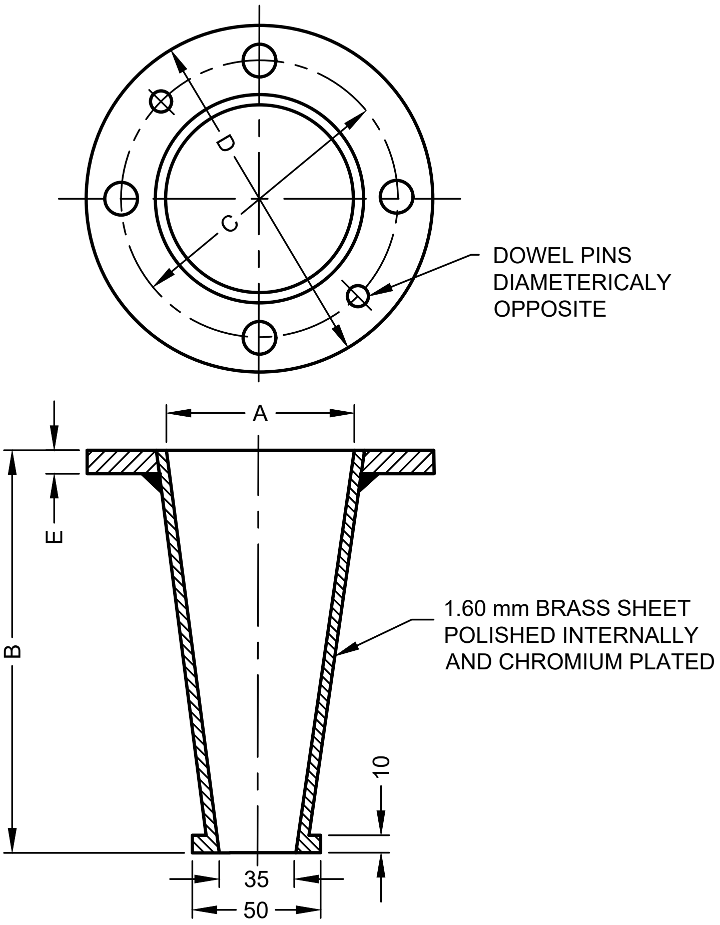
All dimensions in millimetres.

FIG. 1 GONELL ELUTRIATOR ASSEMBLY



All dimensions in millimetres

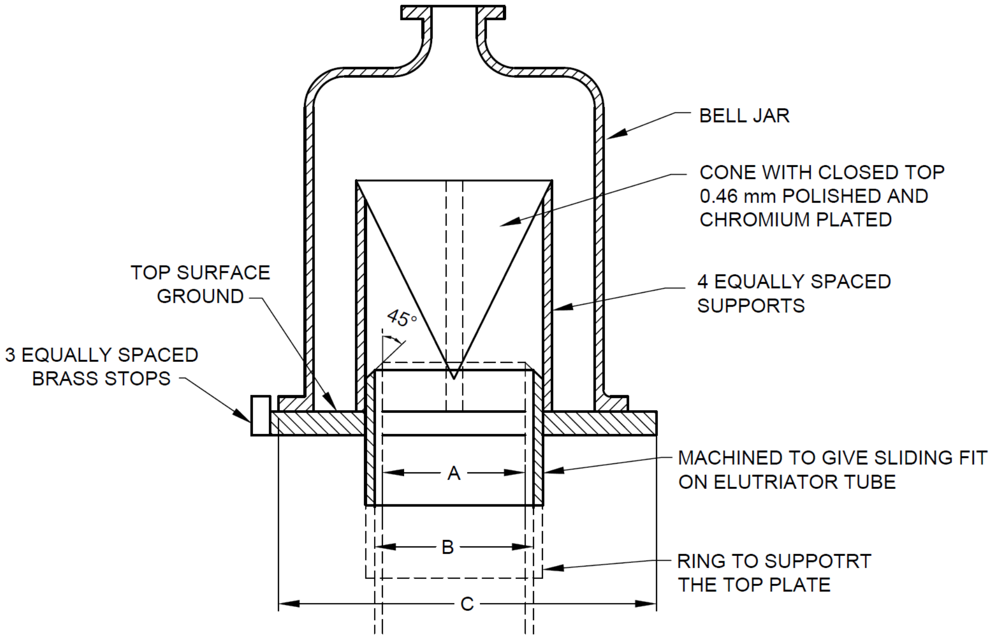
Fig. 2 Details of Powder Container of Gonell Elutriator


D
C
DOWEL PINS DIAMETERICALY OPPOSITE
A
E
B
1.60 mm BRASS SHEET POLISHED INTERNALLY AND CHROMIUM PLATED
10
35
50

DIMENSION	140 mm ADAPTOR	70 mm ADAPTOR
A	140	70
B	300	100
C	170	100
D	190	120
E	6	6

All dimension in millimetres.

FIG. 3 CONICAL ADAPTOR OF GONELL ELUTRIATOR


BELL JAR
CONE WITH CLOSED TOP 0.46 mm POLISHED AND CHROMIUM PLATED
4 EQUALLY SPACED SUPPORTS
TOP SURFACE GROUND
3 EQUALLY SPACED BRASS STOPS
45°
MACHINED TO GIVE SLIDING FIT ON ELUTRIATOR TUBE
RING TO SUPPOTRT THE TOP PLATE
A
B
C

APPROXIMATE DIMENSIONS		
A	*B*	*C*
140	146	248
70	73	210
35	38	210

All dimensions in millimetres.

FIG. 4 DETAILS OF TOP PLATE AND BELL JAR OF GONELL ELUTRIATOR

Table 1 Periods of Elutriation

(*Clauses* 9.2.3.2 *and* 9.2.3.3)

Sl No.	**Stokes Diameter**	**Diameter of Tube**	**Elutriation Periods,** Min		**Settling Time**	
	microns	mm	First	Subsequent	min	s
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	5	140	60	30	13	45
ii)	10	140	60	30	3	30
iii)	20	70	45	20	0	45
iv)	40	35	30	15	0	10
v)	50	35	20	10	0	9

b) *Air Supply* — A supply of clean dry air at 30 kg/mm^2 is sufficient for most *purposes.*

c) *Flowmeters* — Two, covering the ranges 50 to 500 l/h and 400 to 4 000 l/h, are required.

d) *Balance* — Sensitive to 1 mg when loaded with 100 g.

9.2 Procedure

9.2.1 *Setting of the Apparatus*

Before a test, wash the inner surfaces of the elutriator tubes, cones and sample container with a grease-removing solvent (for example, petroleum ether) and polish them with a soft cloth. Do not lubricate the screw threads.

9.2.2 *Preparation of Analysis Sample*

Prepare the analysis sample and weigh into the powder container as described in **5**.

9.2.3 *Elutriation*

9.2.3.1 Attach the sample container to the 140 mm elutriator tube and connect the air supply. Adjust the rate through the tube so that the mean velocity of the air in the tube is equal to the free-falling velocity of the largest particle in the smallest size fraction (say up to 5 microns). Switch on the tube vibrator and proceed with the elutriation.

9.2.3.2 At the end of the appropriate period (*see* Table 1), shut off the air supply and vibrator and allow particles suspended in the air in the tube to settle into the sample container. During the settling time the tube should be tapped periodically with a wooden hammer to release dust from the walls of the tube. Disconnect the sample container and determine the mass of sample retained.

9.2.3.3 Repeat for appropriate periods (*see* Table 1) until the loss of mass of the sample remaining in the container in any given period is not more than one percent of the analysis sample. This is regarded as the ‘end point’.

9.2.3.4 Repeat the same process with the air rate increased to elutriate particles less than, say, 10 microns and again weigh at each stage until the ‘end point’ is reached.

9.2.3.5 Transfer the sample container to the 70 mm tube and repeat the process with the rate adjusted to elutriate particles of the next largest size range, say 20 microns.

9.2.3.6 Transfer the sample container to the 35 mm tube and repeat the process with the rate adjusted to elutriate particles of the next largest size range, say 40 microns.

9.2.4 *Dispersion*

To improve initial dispersion, elutriation may be preceded by a much faster air flow maintained for a period less than that taken to traverse the tube at this speed. In this way the particles will be dispersed but oversize particles will not be carried beyond the tube. The flow is then reduced to the correct elutriation rate.

9.3 Report

9.3.1 Plot the results of the analysis with the micron sizes as abscissae and the percentages undersize as ordinates. Select from the smooth curve (the sizing curve) drawn through the points cumulative percentages corresponding to the series required.

9.3.2 The report shall indicate the method used, the elutriating gas used, if other than air, and the density of the particles.

9.4 Example

9.4.1 A sample of flue dust from pulverized fuel was analyzed. It was first sieved by the end-point rate test with the following result:

Sl No. (1)	*IS Sieve* (2)	*Mass (Percent)* (3)
i)	Retained on 212 µ IS Sieve	0.5
ii)	Passing 212 µ IS Sieve and retained on 150 µ IS Sieve	2.3
iii)	Passing 150 µ IS Sieve and retained on 106 µ IS Sieve	7.3
iv)	Passing 106 µ IS Sieve and retained on 75 µ IS Sieve	5.4
v)	Passing 75 µ IS Sieve	84.5

9.4.2 The sub-sieve portion weighing 1.243 g was elutriated. The values are given in Table 2.

Table 2 Analysis of Sub-sieve Portion by Elutriation

(*Clause* 9.4.2)

Sl No.	Stores Diameter microns	Elutriation Period min	Mass After Cycle g	Reduction in Mass percent	Total Reduction in Mass percent	Cumulative Mass of Undersize percent	Cumulative Mass of Undersize Based on Original Sample percent
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	4.7	60	1.009	18.8	40.8	40.8	34.5
		30	0.927	6.6			
		30	0.862	5.3			
		30	0.804	4.6			
		30	0.769	2.8			
		30	0.746	1.9			
		30	0.736	0.8			
ii)	9.4	60	0.641	7.6	16.4	57.2	48.3
		30	0.597	3.6			
		30	0.568	2.3			
		30	0.552	1.3			
		30	0.538	1.1			
		30	0.532	0.5			
iii)	19	45	0.359	13.9	19.8	77.0	65.1
		20	0.321	3.1			
		20	0.290	2.5			
		20	0.286	0.3			
iv)	37	30	0.160	10.1	13.7	90.7	76.6
		15	0.124	2.9			
		15	0.116	0.7			

9.4.3 The combined results due to sieving and elutriation are given in Table 3.

Table 3 Combined Results of Sieving and Elutriation

(*Clause* 9.4.3)

Sl No.		Particle Size microns	Cumulative Mass of Undersize percent
(1)		(2)	(3)
i)	Sieve	212	99.5
		150	97.2
		106	89.9
		75	84.5
ii)	Stokes[1)]	40	78
		20	66
		10	50
		5	36

[1)] Read off sizing curve.

9.4.4 According to the purpose it may be necessary to apply a correlation to the sieve diameters or to the Stokes diameters or to both (*see* Annex B).

10 ROLLER ELUTRIATOR

10.1 Apparatus

The roller elutriator is an apparatus especially suitable for poorly dispersable particles in the range 5 to 75 microns which cannot be effectively elutriated in the Gonell apparatus.

10.1.1 The method is not suitable for fractionation in the 0 to 5 microns range. An analysis sample of 5 to 15 ml is required. The following are the requirements of the apparatus:

a) *Elutriator* — Consists of four vertical elutriation tubes (diameter ratios 1 : 2 : 4 : 8) which are used one at a time, the one in use being connected at its lower end to a U-tube as shown in Fig. 5. The sample is placed in the U-tube where it is dispersed by the impingement on it of a jet of air from a small diameter nozzle. The displaced particles are carried into the elutriation tube in which a uniform upward air-flow a maintained and the elutriated particles are collected in a thimble filter connected to the top of the tube. Separate thimbles may be used to collect each size fraction, if required.

b) *Air Supply* — The air supply, usually obtained from a compressed air line, is dried in an alumina dryer (with indicating tube) and metered by means of a suitable capillary flowmeter or rotameter. The back-pressure from the air nozzle is measured and the air rate is suitably corrected.

c) *Nozzles* — Ten nozzles are supplied on 0.97, 1.07, 1.17, 1.40, 1.50, 1.78, 2.08, 2.26, 2.44 and 2.64 mm diameters.

d) *Balance* — sensitive to 1 mg when loaded with 0.1 kg.

e) *Vibrating Means* — It is essential to vibrate the blower U-tube to ensure circulation of the sample and to accelerate separation of the particles. The elutriation tube should also be vibrated to dislodge particles adhering to the inner walls. The 'bumping' arrangement shown in Fig. 5 serves to vibrate both U-tube and elutriation tube.

f) All metal parts of the elutriator shall be connected to an electrical earth.

10.2 Procedure

10.2.1 *Preparation of Analysis Sample*

Prepare the analysis sample as described in **5**.

10.2.2 *Elutriation*

Weigh the U-tube or thimble to the nearest milligram. All weighing shall be made as rapidly as possible to avoid moisture pick-up.

10.2.3 Nozzles are selected according to Table 4.

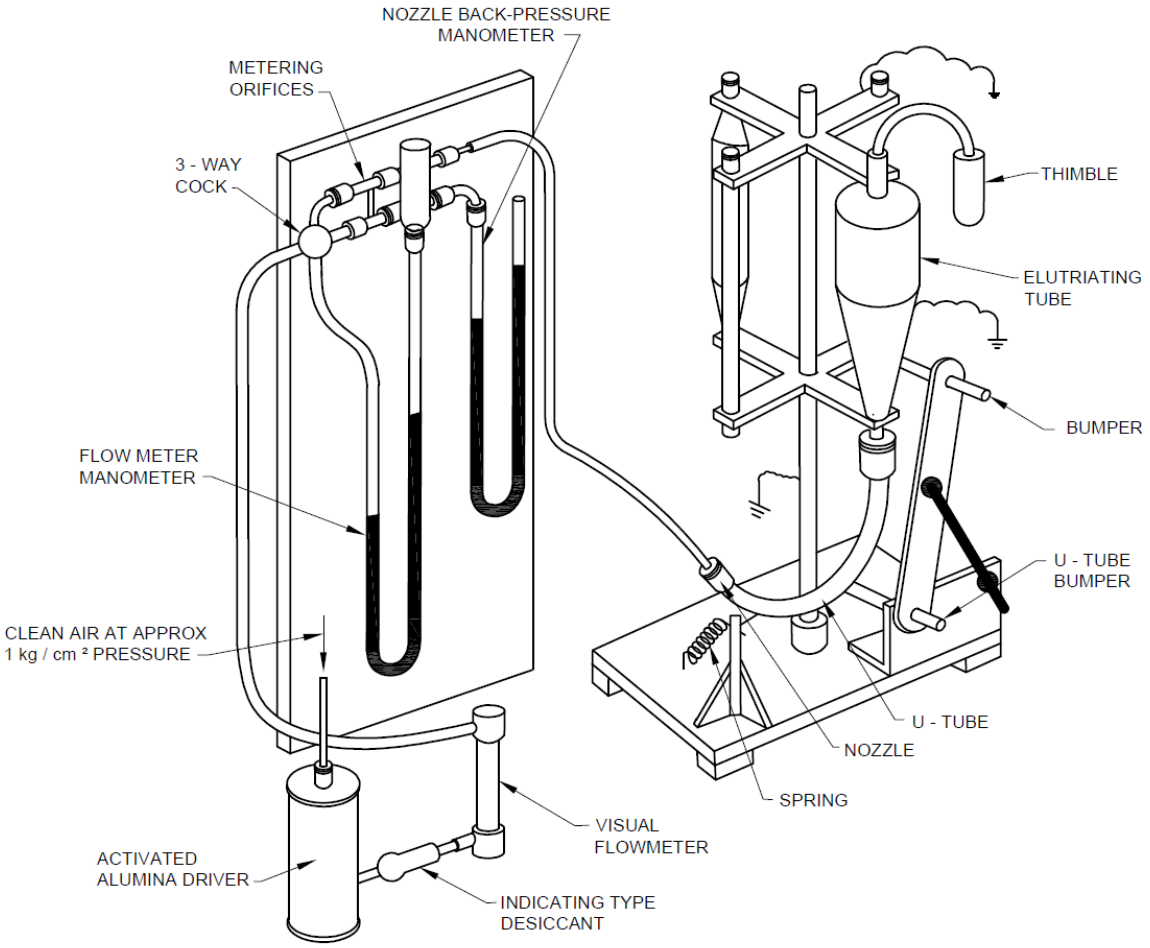


FIG. 5 ROLLER ELUTRIATOR

10.2.4 Connect the U-tube to the largest elutriation tube for elutriating the smallest of the desired size fractions. Pass the dry air over the sample at the appropriate flow rate as calculated from equation (given in **4.2**). After 30 min, stop the flow, disconnect, and rapidly weigh the U-tube or thimble and contents.

10.2.5 Repeat shortening to 15 min periods as the rate of separation falls until the reduction in mass in 15 min is less than one percent of the analysis sample.

10.2.6 Repeat changing the size of the elutriation tube to obtain successive coarser size fractions.

10.2.7 During elutriation, vibrate the U-tube and elutriation tube continuously and rap the latter vigorously with heavy rubber tubing to knock loose powder back into the U-tube.

Table 4 Sizes of Nozzles with Corresponding Air Rate

(*Clause* 10.2.3)

Sl No.	Nozzle Diameter mm	Air Rate l/min
(1)	(2)	(3)
i)	0.97	2.5 to 3.4
ii)	1.07	3.5 to 4.4
iii)	1.17	4.5 to 6.0
iv)	1.40	6.1 to 8.0
v)	1.50	8.1 to 10.0
vi)	1.78	10.1 to 13.0
vii)	2.08	13.1 to 15.0
viii)	2.26	15.1 to 19.0
ix)	2.44	19.1 to 26.0
x)	2.64	26.1 to 35.0

10.3 Report

10.3.1 Plot the results of the analysis with the micron sizes as abscissae and the percentages undersize as ordinates. Select from the smooth curve (the sizing curve) drawn through the points cumulative percentages corresponding to the series required.

10.3.2 The report shall indicate:

a) Method used;
b) The elutriating gas used, if other than air, and
c) The density of the particles.

10.4 Example

10.4.1 The sub-sieve part of a sample of silica weighed 10.268 g. It was elutriated with the roller elutriator with the result given in Table 5.

10.4.2 Combined results are given in Table 6.

10.4.3 According to the purpose it may be necessary to apply a correlation factor to the sieve diameters or to the Stokes diameters or to both (*see* Annex B).

11 MINIATURE ELUTRIATOR

11.1 Apparatus (*see* Fig. 6)

The miniature elutriator is suitable for dealing with powders, which are difficult to disperse, in the size range 10 to 75 microns, and was developed for sizing samples of dust weighing 0.1 g to 0.5 g. An analysis sample of about 0.2 ml is required.

11.1.1 The miniature elutriator consists of a single tube of small dimensions which may be quickly cleaned. The powder is dispersed by a high speed air jet of about 30 m/s velocity from a replaceable jet or nozzle which projects into the powder holder. A fine jet is used for elutriating the smaller particles and a coarser one for the larger particles.

11.1.2 The instrument is not generally suitable when the free-falling velocity is less than 7.5 mm/s in air. This corresponds to a particle size of about 10 microns for a particle density of 2 g/cm^3, and of about 5 micros for a particle density of 8 g/cm^3. The following are the requirements of the apparatus:

a) *Elutriator* — The apparatus consists of a tube preferably of brass 360 mm long and of 25 mm internal dia free from ripples, polished and preferably nickel or chromium plated on the inside, to which is attached a conical tube 110 mm long. An aluminium alloy base, in which the sample is contained, is screwed to the conical portion. Either a fine jet of 0.7 mm internal diameter or a coarse jet of 2.5 mm internal diameter can be screwed into the end of the air delivery tube according to the air rate required. The elutriator tube is mounted vertically on a sample stand, the tube being attached to the stand by four flat springs. The tube vibrates slightly when tapped and this helps to dislodge dust sticking to the walls.

Table 5 Typical Example of Analysis of a Powder by Roller Elutriator

(*Clause* 10.4.1)

Sl No. (1)	**Stores Diameter** microns (2)	**Mass of Sample** g (3)	**Reduction in Mass** g (4)	**Total Reduction in Mass** g (5)	**Cumulative Mass of Undersize** percent (6)	**Cumulative Mass of Undersize Based on Original Sample** percent (7)
i)	4.7	10.268			16.8	16.1
		9.362	0.906	0.906		
		8.956	0.406	1.312		
		8.717	0.239	1.551		
		8.586	0.131	1.682		
		8.539	0.047	1.729		
ii)	6.6	8.216	0.323	2.052	21.9	21.0
		8.066	0.150	2.202		
		8.016	0.050	2.252		
iii)	9.4	7.310	0.706	2.958	29.5	28.4
		7.230	0.080	3.038		
iv)	13	6.503	0.727	3.765	38.7	37.1
		6.363	0.140	3.905		
		6.296	0.067	3.972		
v)	19	5.629	0.667	4.639	52.2	50.0
		5.263	0.366	5.005		
		4.959	0.304	5.309		
		4.921	0.038	5.347		
vi)	27	3.924	0.997	6.344	66.8	64.0
		3.654	0.270	6.614		
		3.473	0.181	6.795		
		3.400	0.073	6.868		
vii)	37	2.400	1.000	7.868	82.7	79.2
		2.111	0.289	8.157		
		1.842	0.269	8.426		
		1.792	0.050	8.476		
viii)	53	0.798	0.994	9.470	94.8	91.0
		0.644	0.154	9.624		
		0.552	0.092	9.716		

Table 6 Combined Results of Sieving and Elutriation

(*Clause* 10.4.2)

Sl No. (1)	Particle Size percent (2)		Cumulative Mass of Undersize percent (3)
i)	Sieve	212	100.0
		150	99.9
		106	99.4
		75	95.9
ii)	Stokes	40	83
		20	52
		10	30
		5	17

11.2 Procedure

11.2.1 *Setting of Apparatus*

Wash the inner surface of the elutriator tube, cone and sample holder with a suitable grease-removing solvent (for example, petroleum ether) and then polish with a soft cloth. Do not lubricate the screw threads.

11.2.2 *Preparation of the Analysis Samples* — Prepare the analysis sample k described in **5**.

11.2.2.1 The fine jet should not be immersed in the powder when the ample holder is screwed into position. The maximum level to which the sample holder may be filled with powder shall be indicated on the sample holder.

11.2.3 *Elutriation* — Connect the air entry tube to the air supply. Adjust flow rate Q a flow rate corresponding to the free-falling velocity of the largest particles to be driven off (*see* equation at **4.2**).

11.2.3.1 Maintain the rate for 15 min. Rap the elutriator tube at intervals, especially for a few seconds before the air is turned off to dislodge Experience has shown material sticking loosely to the walls of the elutriator. That the material remaining on the walls after rapping is smaller than the Elected size which is being elutriated.

11.2.3.2 Dry the sample holder and its contents and weigh.

11.2.3.3 Repeat weighing at 15 min intervals until two consecutive weighing shown a loss of not more than one percent of the initial mass of the test portion.

11.2.3.4 Double the air rate to elutriate the next size range and determine the loss of mass corresponding to this size range as before. Continue in the same manner to elutriate successively larger size fractions until whole of the sample has been elutriated.

11.3 Report

11.3.1 Plot the results of the analysis with the micron sizes as abscissae and the percentages undersize as ordinates. Select from the smooth curve (the sizing curve) drawn through the points cumulative percentages corresponding to the series required.

11.3.2 The report shall indicate:

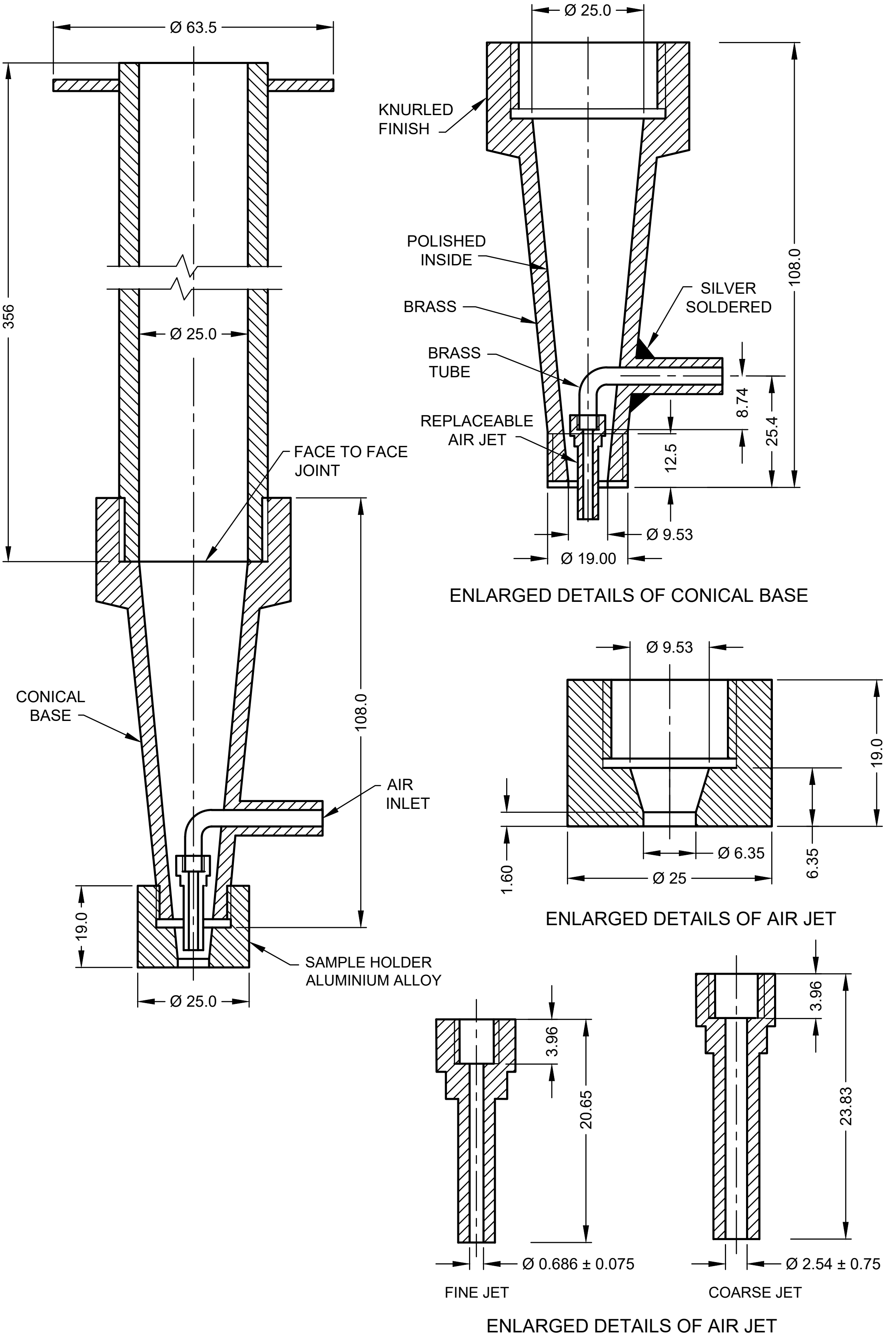
a) method used;
b) the elutriating gas used, if other than air; and
c) the density of the particles.

11.4 Example

11.4.1 The sub-sieve part of a sample of silica weighed 0.252 5 g. It was elutriated with the miniature elutriator with the result given in Table 7.

11.4.2 The combined results are given in Table 8.

11.4.3 According to the purpose it may be necessary to apply a correlation factor to the sieve diameters or to the Stokes diameter or to both (*see* Annex B).



All dimensions in millimetres.

Fig. 6 Miniature Elutriator

Table 7 Typical Example of Analysis of a Powder by Miniature Elutriator

(*Clause* 11.4.1)

Sl No. (1)	Stokes Diameter Microns (2)	Mass of Sample Holder g (3)	Reduction in Mass g (4)	Total Reduction in Mass g (5)	Cumulative Mass of Undersize percent (6)	Cumulative Mass of Undersize Based on Original Sample percent (7)
i)	9.4	18.988 0	0.032 0	0.032 0	28.1	26.9
		18.956 0	0.032 0	0.032 0		
		18.934 2	0.021 8	0.053 8		
		18.928 6	0.005 6	0.059 4		
		18.923 0	0.005 6	0.065 0		
		18.917 8	0.005 2	0.070 2		
		18.917 1	0.000 7	0.070 9		
ii)	13	18.906 9	0.010 2	0.081 1	41.4	39.7
		18.894 2	0.021 7	0.093 8		
		18.884 6	0.009 6	0.103 4		
		18.883 8	0.000 8	0.104 2		
iii)	19	18.863 1	0.021 7	0.125 9	51.4	49.3
		18.859 8	0.002 3	0.128 2		
		18.858 7	0.001 1	0.129 3		
iv)	26	18.835	0.023 6	0.152 9	68.0	65.2
		18.817 8	0.017 3	0.170 2		
		18.816 2	0.001 6	0.171 8		
v)	37	18.785 8	0.030 4	0.202 2	83.3	79.9
		18.778 8	0.007 0	0.209 2		
		18.7779	0.000 9	0.210 1		
vi)	53	18.743 0	0.034 9	0.245 0	97.1	93.1
		18.742 7	0.000 3	0.245 3		

Table 8 Combined Results of Sieving and Elutriation

(*Clause* 11.4.2)

Sl No. (1)	Particle Size microns (2)		Cumulative Mass of Undersize percent (3)
i)	Sieve	212	100.0
		150	99.9
		106	99.4
		75	95.9
ii)	Stokes	40	78
		20	54
		10	29

ANNEX A

(*Clause* 4.1.1)

FREE-FALLING DIAMETERS OF PARTICLES WHEN STOKES LAW IS NOT VALID

A-1 DETERMINATION OF TRUE FREE-FALLING DIAMETER

A-1.1 Stokes law does not apply when the Reynolds number for particle motion exceeds 0.2 and diameters calculated thereby are smaller than the correct values. The true free-falling diameter in microns may be determined from Table 9 which has been calculated for air at 27 °C temperature and 760 mm mercury pressure. The values considered for g, ρ and η respectively are 978.638 cm.s^2, 1.176 × 10^{-3} g/cm^3 and 1.851 6 × 10^{-4} poise.

A-1.2 The true free-falling diameters should be used if the results of elutriation analysis are plotted graphically, for example, for correlation of the results with a sieving analysis.

Table 9 Values of True Free-falling Diameter for Corresponding Stokes Diameter

(*Clause* A-1.1)

Sl No.	Stokes Diameter microns	True Free-Falling Diameter in Air, microns				
		For Particle Density (g/cm^3)				
		1.3	2.7	4.0	8.9	19.9
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	75	79.8	84.3	88.2	99.6	117.7
ii)	63	65.4	67.9	70.0	76.9	88.2
iii)	53	54.2	55.5	56.6	60.6	67.6
iv)	45	45.7	46.3	46.9	49.1	53.4
v)	37.5	37.9	38.2	38.5	39.6	41.9
vi)	31.5	31.7	31.9	32.0	32.6	33.8
vii)	26.5	26.6	26.7	26.8	27.0	27.7
viii)	22.5	22.5	22.6	22.7	22.8	23.1

ANNEX B

(*Clauses* 9.4.4, 10.4.3 *and* 11.4.3)

CORRELATION OF RESULTS FROM DIFFERENT METHODS OF SIZE DETERMINATION

B-1 GENERAL

The series of specifications of Indian Standard test methods for powder properties are relevant to particles smaller than 1 000 microns in size. A number of methods (sieving, sedimentation, elutriation, the microscope) are specified for the determination of particle size. No single method is applicable to the whole range of sizes 1 000 to 1 microns so that, if a powder being analysed is composed of particles of a wide range of sizes, it is necessary to combine the analyses by two or more different methods in order to establish the distribution in full. In general, a particle size determination will consist of a sieving of the material down to 75 microns combined with an analysis of the fraction below 75 microns either by sedimentation or elutriation or by microscope.

B-2 FACTORS AFFECTING RESULTS FROM DIFFERENT METHODS

B-2.1 In a particle size determination the particle size is not measured directly but some size-dependent property of the particle is assessed and from this the size of the particle is deduced. This is true even for the microscope method where it is the size of an enlarged image of the particle that is assessed and not the size of the particle itself; the distinction is not important, however, except for sizes near the limit of resolution of the optical system. In sieving, a particle is classified by its ability to pass through an aperture of given size, in sedimentation by its free-falling speed through a stationary fluid, and in elutriation by the upward velocity of a fluid necessary to prevent the particle falling.

B-2.2 If a particle is spherical, there is no difficulty in relating the results obtained by different methods of size determination. Because of its symmetry a sphere appears of the same size whatever its orientation and this size is defined completely by its diameter. The diameter is easily measured under the microscope; the limiting diameter of sphere that will pass through a given sieve aperture is well defined; and Stokes law relates the free-falling speed of a sphere measured either by sedimentation or by elutriation to its diameter. The same diameter will be assigned to a sphere whatever the method of determination and results obtained by different methods may be combined directly.

B-2.3 Although an irregular particle has a definite volume and surface area the particle cannot be defined in geometric terms and one cannot assign to it a diameter (or a length, breadth and thickness) that enables its volume or surface area to be accurately determined. The size-dependent properties of the particle can still be determined and it is often convenient to represent the particle not by the measured property but by a size. It is customary for the size chosen to be the diameter of the sphere that exhibits the same property as the particle that is the sphere that has the same projected area, or that just passes through the same sieve aperture or that falls at the same speed through a fluid. However, the sphere that is equivalent to a particle in regard to one size-dependent property (say, projected area) is not necessarily of the same diameter as the sphere equivalent in regard to some other property (say, free-falling speed). An irregular particle, therefore, is assigned different sizes by different methods of determination and results obtained by different methods cannot be combined directly. A further point is that the size-dependent properties of a non-spherical particle depend on its orientation so that its size even as determined by a single method is no longer a constant of the particle.

B-2.4 The discrepancy between the sizes assigned to a particle by different methods depends on the departure of the particle from sphericity. It is possible to combine the sizes from different methods to give non-dimensional parameters known as shape-factors, which serve to characterize the shape of the particle. A single shape-factor does not characterize a particle exclusively and the particle has as many shape-factors as there are pairs of methods of determining its size. In general, especially in the sub-sieve range, information is obtained not on the sizes of individual particles but on the proportions, either by number or by mass, of particles in a series of size classes. Shape-factors are usually, therefore, the ratio for a group of particles of the mean sizes determined by two different methods.

B-2.5 Three situations demanding a knowledge of shape-factors may arise and they are as follows:

a) It may be necessary to convert from a size distribution by number to one by mass, or vice versa. The conversion is usually made by assuming that particles of all sizes have the same shape in the sense that the volume of the particle is proportional to the cube of the measured diameter. It is further assumed that all particles have the same shape; the relationship of measured diameter to volume has to be known for each size class.

b) It may be necessary to estimate some size-dependent property of a powder where it cannot be determined directly.

c) It may be necessary to combine size distributions determined by different methods.

B-3 CORRELATION FACTORS FOR DIFFERENT METHODS

B-3.1 To assist in the situations given in **B-2.5**(b) and **B-2.5**(c), recommended factors are shown for use, in the absence of specific knowledge, in correlating the following particle diameters:

a) Sieve — Nominal sieve aperture through which particle just passes.

b) Projected — Diameter of circle of area equal to the projected area of particle resting in its most stable position.

c) Stokes — Diameter of sphere of equal density having the same free-falling velocity as the particle in a fluid under identical conditions within the range of Stokes law.

d) The conversion values are given below:

To Convert	*Multiply by*
Sieve to projected	1.40
Sieve to Stokes	0.94
Projected to sieve	0.71
Projected to Stokes	0.67
Stokes to sieve	1.07
Stokes to projected	1.50

Example

The mean diameter of particles which would just pass a 75 micron sieve aperture would match a 105 micron diameter circle by the microscope, and their mean Stokes diameter would be 705 microns.

B-3.2 The factors should be applied with caution especially if there is any suspicion that the particles of the powder under test are of extreme shapes, for example, if they have cleavage planes or are acicular. It is highly preferable to use correlation factors specifically determined for the powder. Possible methods of establishing factors are:

a) to overlap the methods of size determination so that one or more size classes are assessed by both methods; and

b) to size a sample of the material similar to the sample under test by both methods of size determination.

ANNEX C

(*Foreword*)

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